CHAPTER 5 NEWTON'S LAWS OF MOTION

Select odd-numbered solutions, marked with a dagger (†), appear in the Student Solutions Manual, available for purchase. Answers to all solutions below are underscored.

5-1. $m = 975\text{ lb} \times \dfrac{1\text{ kg}}{2.205\text{ lb}} = \underline{442\text{ kg}}.$

5-2. $m_{atom} = m_p + m_e = 1.673 \times 10^{-27}\text{ kg} + 9.11 \times 10^{-31}\text{ kg} = 1.67 \times 10^{-27}\text{ kg}.$ To three significant digits the mass of the electron is negligible compared to the mass of the proton.

$$N = \frac{1.0\text{ kg}}{1.67 \times 10^{-27}\text{ kg/atom}} = \underline{6.0 \times 10^{26}\text{ atoms.}}$$

5-3. $m_{atom} = 8(m_p + m_n + m_e) = 8(1.673 \times 10^{-27}\text{ kg} + 1.675 \times 10^{-27}\text{ kg} + 9.11 \times 10^{-31}\text{ kg}) = 2.68 \times 10^{-26}\text{ kg}.$

$$N = \frac{1.0\text{ kg}}{2.68 \times 10^{-26}\text{ kg/atom}} = \underline{3.7 \times 10^{25}\text{ atoms.}}$$

5-4. The forces must have equal magnitudes. Thus $m_{boy}\left|a_{boy}\right| = m_{girl}\left|a_{girl}\right|.$

$$m_{girl} = \frac{m_{boy}\left|a_{boy}\right|}{\left|a_{girl}\right|} = \frac{50\text{ kg} \times 7\text{ m/s}^2}{8.2\text{ m/s}^2} = \underline{43\text{ kg}}.$$

†5-5. $\bar{a} = \dfrac{v_2 - v_1}{\Delta t} = \dfrac{(80\text{ km/h} - 0\text{ km/h})}{5.8\text{ s}} \times \dfrac{1000\text{ m}}{\text{km}} \times \dfrac{1\text{h}}{3600\text{ s}} = 3.83\text{ m/s}^2.$ Final answer $= \underline{3.8\text{ m/s}^2}.$ To find the magnitude of the average force, use the three-digit intermediate result for $\bar{a}$: $\bar{F} = m\bar{a} = 1620\text{ kg} \times 3.83\dfrac{\text{m}}{\text{s}^2} = 6205\text{ N}.$ Final answer $= \underline{6.2 \times 10^3\text{ N}}.$

5-6. $a = F/m = 2.7 \times 10^5\text{ N}/1.6 \times 10^4\text{ kg} \underline{= 17\text{ m/s}^2}$

5-7. $\Delta v = 50\text{ km/h} - 0\text{ km/h} = 50\text{ km/hr} = 13.9\text{ m/s}$
$\bar{F} = m\bar{a} = m\Delta v/\Delta t = 57\text{ kg}(13.9\text{ m/s})/0.12\text{ s}$ $\underline{= 6.6 \times 10^3\text{ N, which is 12 times the weight.}}$

5-8. $m = 16\,000$ metric tons $\times 10^3$ kg/metric ton $= 1.6 \times 10^7$ kg.

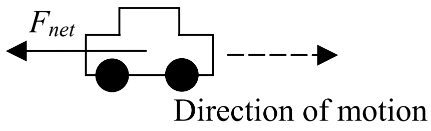
$$\bar{a} = \frac{\bar{F}}{m} = \frac{6.7 \times 10^5\text{ N}}{1.6 \times 10^7\text{ kg}}.\ \underline{\bar{a} = 0.0419\text{ m/s}^2}.\ \underline{\text{Final result} = 0.042\text{ m/s}^2}.$$

$$v = v_0 + \bar{a}t \Rightarrow t = \frac{v - v_0}{\bar{a}} = \frac{50\text{ km/h} - 0}{0.0419\text{ m/s}^2} \times 1000\frac{\text{m}}{\text{km}} \times \frac{1\text{h}}{3600\text{ s}} = 332\text{ s}.$$ Final result: $\underline{t = 5.5\text{ min}}$.

†5-9. Vector note: "Decelerates" is a nontechnical way of stating that the acceleration points in the opposite direction from the velocity, causing the speed to decrease. If we take the positive direction for vectors to be in the direction of motion, then *a* must be represented by a negative number, and the net force will also be a negative number. A "free-body" diagram is shown to illustrate these concepts. Thus

$$F_{net} = ma = 1500\text{ kg} \times (-8.0\text{ m/s}^2) = \underline{-1.2 \times 10^3\text{ N}}.$$

Again, the – sign means the force points in the opposite direction from the original motion.



5-10. $v^2 = v_0^2 + 2ax.\ v_0 = 50\text{ km/h} = 13.9\text{ m/s},\ v = 0 \Rightarrow a = \dfrac{v^2 - v_0^2}{2x} = \dfrac{0 - (13.9\text{ m/s})^2}{2(0.40\ \ \text{m})}$

$= -241\text{ m/s}^2$. (Vector note: The – sign means the acceleration is in the opposite direction from the motion.) The magnitude of the net force is $|\mathbf{F}| = m|\mathbf{a}| = (1400\text{ kg})(241\text{ m/s}^2) = \underline{3.4 \times 10^5\ \text{N}}$.

5-11. $v_0 = 174$ km/h = 48.3 m/s. Since $v^2 - v_0^2 = 2a(x - x_0)$,

$a = \dfrac{-v_0^2}{2(x - x_0)} = \dfrac{-(48.3\text{ m/s})^2}{2 \times 0.66\text{ m}} = \underline{-1.8 \times 10^3\text{ m/s}^2}$

$F = ma = -75\text{ kg} \times 1.8 \times 10^3\text{ m/s}^2 = \underline{-1.3 \times 10^5\text{ N}}$

5-12. We calculated that it had an acceleration = 3.26×10^4 m/s²
$F = ma = 45\text{ kg} \times 3.26 \times 10^4\text{ m/s}^2 = \underline{1.46 \times 10^6\text{ N}}$.

5-13. $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{30\text{ m/s} - 0\text{ m/s}}{0.060\text{ s}} = 500\text{ m/s}^2.\ \bar{F} = m\bar{a} \Rightarrow \bar{F} = 0.07\text{ kg} \times 500\text{ m/s}^2 = \underline{35\text{ N}}$

5-14. $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{22\text{ m/s} - 0\text{ m/s}}{0.20\text{ s}} = 110\text{ m/s}^2.\ \underline{\bar{F} = m\bar{a} = 0.035\text{ kg} \times 110\text{ m/s}^2 = 3.9\text{ N}}$. Vector note:

Becasuse both $\bar{a}$ and $\bar{F}$ are positive, they point in the same direction, as required by Newton's Second Law.

†5-15. $\bar{a} = \dfrac{\Delta v}{\Delta t}$. First interval: $\bar{a}_1 = \dfrac{10.0\text{ m/s} - 15.0\text{ m/s}}{1.2\text{ s}} = -4.17\text{ m/s}^2$. Final result = $\underline{-4.2\dfrac{\text{m}}{\text{s}^2}}$. Second interval: $\bar{a}_2 = \dfrac{5.0\text{ m/s} - 10.0\text{ m/s}}{2.1\text{ s}} = -2.38\text{ m/s}^2$. Final result = $\underline{-2.4\text{m/s}^2}$. During the first interval, $\bar{F}_1 = m\bar{a}_1 = 240\text{ kg} \times (-4.17\text{ m/s}^2) = \underline{-1.0 \times 10^3\text{ N}}$. During the second interval, $\bar{F}_2 = m\bar{a}_2 = 240\text{ kg} \times (-2.38\text{ m/s}^2) = \underline{-5.7 \times 10^2\text{ N}}$. Vector note: The – signs imply that the accelerations and forces point in the opposite direction from the motion.

5-16. $\bar{a} = \dfrac{\bar{F}}{m} = \dfrac{55\text{ N}}{0.057\text{ kg}} = 2037\text{ m/s}^2.\ v_{final} = v_{initial} + \bar{a}\Delta t = 0 + 2037\text{ m/s}^2 \times 0.13\text{ s} = 264.8\text{m/s}.$

Final answer = $\underline{2.6 \times 10^2\text{ m/s}}$.

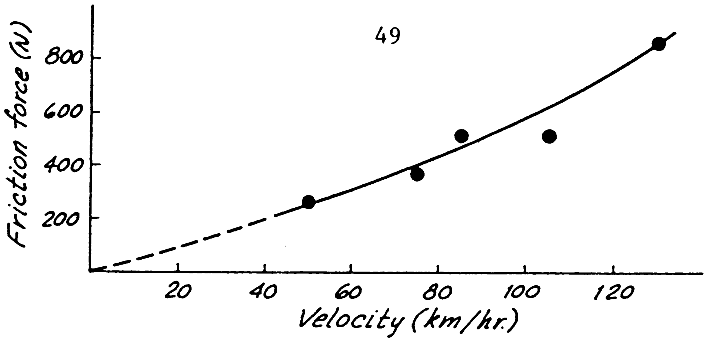
5-17. The forces must have equal magnitudes, so $|F_{astronaut}| = |F_{satellite}|$.

$m_{astronaut}|a_{astronaut}| = m_{satellite}|a_{satellite}|.\ |a_{satellite}| = \dfrac{m_{astronaut}|a_{astronaut}|}{m_{satellite}} = \dfrac{95\text{ kg} \times 0.50\text{ m/s}^2}{750\text{ kg}} =$

$\underline{0.063\text{ m/s}^2}$.

5-18.

t(s)	a(ms^{-2})	$F = ma$(N)	Velocity (km/hr)
0	0.74	860	130
10	0.44	510	105
20	0.44	510	85
30	0.31	360	75
40	0.22	260	50



†5-19. For the first 0.30-s interval, $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{638 \text{ m/s} - 657 \text{ m/s}}{0.30 \text{ s}} = -63.3 \text{ m/s}^2$. The mass is

$m = 100 \text{ lb} \times \dfrac{1 \text{ kg}}{2.205 \text{ lb}} = 45.4 \text{ kg}$. $\bar{F} = m\bar{a} = 45.4 \text{ kg} \times (-63.3 \text{ m/s}^2) = \underline{-2.9 \times 10^3 \text{ N}}$.

For the last 0.30 s interval, $\bar{a} = \dfrac{502 \text{ m/s} - 514 \text{ m/s}}{0.30 \text{ s}} = \underline{-40.0 \text{ m/s}^2}$.

$\bar{F} = m\bar{a} = 45.4 \text{ kg} \times (-40.0 \text{ m/s}^2) = \underline{-1.8 \times 10^3 \text{ N}}$. Vector note: The – signs imply that the accelerations and forces point in the opposite direction from the motion.

5-20. $\mathbf{v} = \dfrac{d\mathbf{r}}{dt} = \dfrac{d}{dt}\left[(5.0 \times 10^4 t)\mathbf{i} + (2.0 \times 10^4 t - 2.0 \times 10^5 t^2)\mathbf{j} - (4.0 \times 10^5 t^2)\mathbf{k}\right]$

$= \left(5.0 \times 10^4\right)\mathbf{i} + \left(2.0 \times 10^4 - 4.0 \times 10^5 t\right)\mathbf{j} - \left(8.0 \times 10^5 t\right)\mathbf{k}$ m/s. $\mathbf{a} = \dfrac{d\mathbf{v}}{dt}$

$= \dfrac{d}{dt}\left[\left(5.0 \times 10^4\right)\mathbf{i} + \left(2.0 \times 10^4 - 4.0 \times 10^5 t\right)\mathbf{j} - \left(8.0 \times 10^5 t\right)\mathbf{k}\right] = 0\mathbf{i} - \left(4.0 \times 10^5\right)\mathbf{j} - \left(8.0 \times 10^5\right)\mathbf{k}$.

$\mathbf{a} = -\left(4.0 \times 10^5\right)\mathbf{j} - \left(8.0 \times 10^5\right)\mathbf{k}$ m/s^2.

$\mathbf{F} = m\mathbf{a} = (1.7 \times 10^{-27} \text{ kg})\left[-\left(4.0 \times 10^5\right)\mathbf{j} - \left(8.0 \times 10^5\right)\mathbf{k} \text{ m/s}^2\right]$

$= -(6.8 \times 10^{-22})\mathbf{j} + (1.36 \times 10^{-21})\mathbf{k}$ N. Final result $= -(6.8 \times 10^{-22})\mathbf{j} + (1.4 \times 10^{-21})\mathbf{k}$ N.

$|\mathbf{F}| = \sqrt{(6.8 \times 10^{-22})^2 + (1.36 \times 10^{-21})^2} \text{ N} = \underline{1.5 \times 10^{-21} \text{ N}}$.

†5-21. $v = \dfrac{dx}{dt} = \dfrac{d}{dt} x_0\left[1 - \cos(bt)\right] = 0 + bx_0 \sin(bt)$. $\underline{v = bx_0 \sin(bt)}$.

$\underline{a = \dfrac{dv}{dt} = \dfrac{d}{dt} bx_0 \sin(bt) = b^2 x_0 \cos(bt)}$. $\underline{F = ma = mb^2 x_0 \cos(bt)}$.

$x = x_0\left[1 - \cos(bt)\right] \Rightarrow x_0 \cos(bt) = -(x - x_0)$. $\underline{F = -mb^2(x - x_0)}$. This type of motion, in which the magnitude of the force is proportional to the distance from an equilibrium point and always points in the opposite direction from the displacement, turns out to be very important in science.

5-22. $F_{net} = ma = 1200 \text{ kg} \times 7.8 \text{ m/s}^2 = 9.36 \times 10^3 \text{ N}$. $\underline{F_{wheel} = \dfrac{F_{net}}{4} = 2.3 \times 10^3 \text{N}}$.

5-23. 2300 children means 1150 children on each side. Therefore, the force exerted by each side is $1150 \times 130 \ \underline{= 150{,}000 \text{N}}$ tension in rope. No, it was *not* safe.

5-24. The component of each pull along the direction of motion is $460\cos 30° \text{ N} = 398 \text{ N}$. The components perpendicular to the direction of motion cancel. The net force on the barge is $2 \times 298 \text{ N} = 596 \text{ N}$. The acceleration of the barge is $a = \frac{F_{net}}{m} = \frac{596 \text{ N}}{1800 \text{ kg}} = \underline{0.331 \text{ m/s}^2}$.

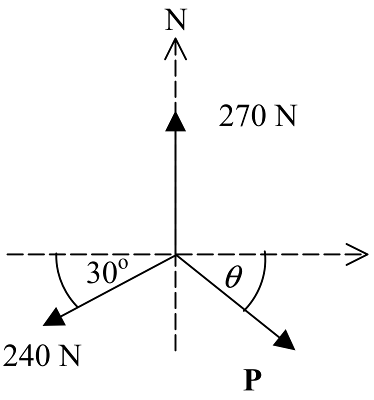
†5-25. Find the east and south components of **P** that will make the net force zero:

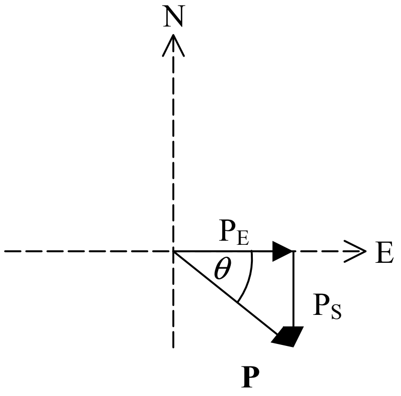
$F_{net,E} = \sum F_E = P_E - (240 \text{ N})\cos 30° = 0 \Rightarrow P_E = 208 \text{ N}.$

$F_{net,N} = \sum \text{F}_N = 270 \text{ N} - P_S - (240 \text{ N})\sin 30° = 0 \Rightarrow P_S = 150 \text{ N}.$

$|\mathbf{P}| = \sqrt{P_E^2 + P_S^2} = \sqrt{(208 \text{ N})^2 + (150 \text{ N})^2} = \underline{256 \text{ N}}.$

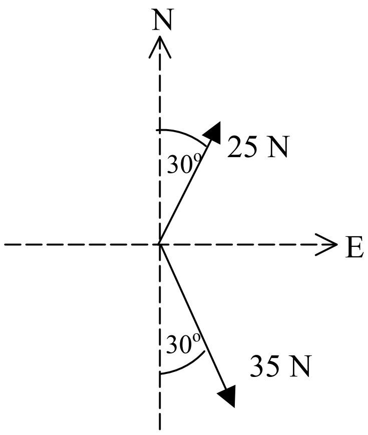
$\theta = \tan^{-1}\frac{P_S}{P_E} = \tan^{-1}\frac{208 \text{ N}}{150 \text{ N}} = \underline{54.2°}$ $\underline{(54.2° \text{ S of E})}$.

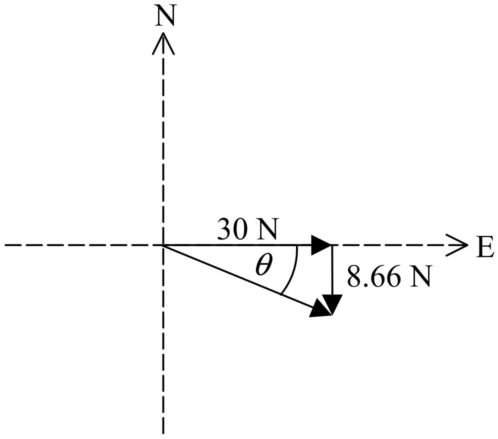




5-26. The net north (y) component of the total force is $F_{net,N} = (25 \text{ N})\cos 30° - (35 \text{ N})\cos 30°$. $= -8.66$ N. (The – sign means the net north-south force component points south.) The net east (x) component of the force is $F_{net,E} = (25 \text{ N})\sin 30° + (35 \text{ N})\sin 30° = 30 \text{ N}$. The magnitude of the net force is $|\mathbf{F}_{\text{net}}| = \sqrt{F_{net,E}^2 + F_{net,N}^2} = \sqrt{(30 \text{ N})^2 + (-8.66 \text{ N})^2} = \underline{31 \text{ N}}$. The direction is given by

$\theta = \tan^{-1}\frac{F_S}{F_E} = \tan^{-1}\frac{-8.66 \text{ N}}{30 \text{ N}} = \underline{-16°}$. $\underline{\text{The direction of the net force is 16° S of E}}$.





†5-27. The net force in the east direction is $F_{net,E} = (2500\ \text{N})\sin 15° + (3200\ \text{N})\sin 30° = 2247\ \text{N}$. The net force in the north direction is $F_{net,N} = (2500\ \text{N})\cos 15° + (3200\ \text{N})\cos 30° = 5186\ \text{N}$.

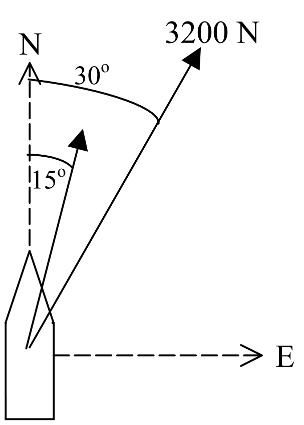
To find the east and north components of acceleration, divide each force component by the mass:

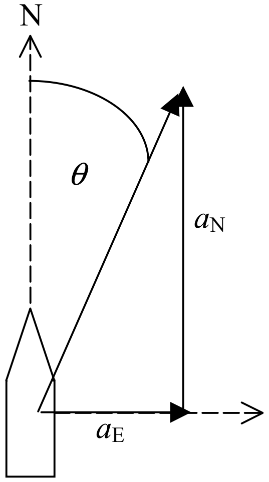
$$a_E = \frac{F_{net,E}}{m} = \frac{2247\ \text{N}}{1400\ \text{kg}} = 1.605\ \text{m/s}^2 \qquad a_N = \frac{F_{net,N}}{m} = \frac{5186\ \text{N}}{1400\ \text{kg}} = 3.704\ \text{m/s}^2$$

$$a = \sqrt{a_E^2 + a_N^2} = \sqrt{\left(1.605\ \text{m/s}^2\right)^2 + \left(3.704\ \text{m/s}^2\right)^2} = \underline{4.037\ \text{m/s}^2}.$$

$$\theta = \tan^{-1}\frac{a_E}{a_N} = \tan^{-1}\frac{1.605}{3.704} = \underline{23.43°}.$$

This is 23.43° E of N.





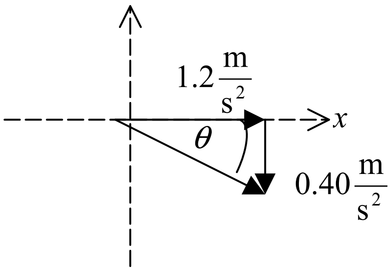
5-28. $\mathbf{F}_{net} = \mathbf{F}_1 + \mathbf{F}_2 = \left[(4.0\ \text{N})\mathbf{i} + (3.0\ \text{N})\mathbf{j}\right] + \left[(2.0\ \text{N})\mathbf{i} - (5.0\ \text{N})\mathbf{j}\right] = (6.0\ \text{N})\mathbf{i} - (2.0\ \text{N})\mathbf{j}$

$$\mathbf{a} = \frac{\mathbf{F}_{net}}{m} = \frac{(6.0\ \text{N})\mathbf{i} - (2.0\ \text{N})\mathbf{j}}{5\ \ \text{kg}} = \left(1.2\ \text{m/s}^2\right)\mathbf{i} - \left(0.40\ \text{m/s}^2\right)\mathbf{j}$$

$$|\mathbf{a}| = \sqrt{\text{a}_x^2 + \text{a}_y^2} = \sqrt{\left(1.2\ \text{m/s}^2\right)^2 + \left(0.40\ \text{m/s}^2\right)^2} = \underline{1.3\ \text{m/s}^2}.$$

$$\theta = \tan^{-1}\frac{\text{a}_y}{\text{a}_x} = \tan^{-1}\frac{-0.40}{1.2} = \underline{-18°}.$$

This is 18° *below* the +*x* axis.

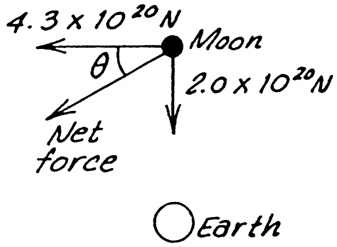

$1.2\frac{\text{m}}{\text{s}^2}$
x
θ
$0.40\frac{\text{m}}{\text{s}^2}$

5-29. By vector addition $\mathbf{F}_{\text{net}} = \mathbf{F}_{\text{Sun}} + \mathbf{F}_{\text{Moon}}$

$\mathbf{F}_{\text{net}} = \sqrt{(4.3 \times 10^{20})^2 + (2.0 \times 10^{20})^2}\ \text{N}$

$\underline{= 4.7 \times 10^{20}\,\text{N}}$

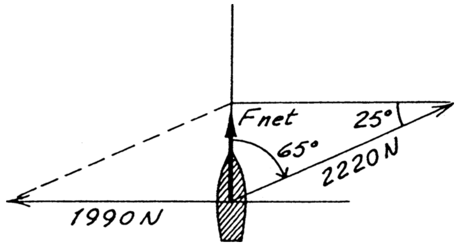
And the angle it makes with line of force to Sun is $\theta = \tan^{-1} 2.0/4.3 = \underline{25°}$.



5-30. The net force is simply given by $\mathbf{F}_{\text{water}} + \mathbf{F}_{\text{wind}}$
Then magnitude, by law of cosines, is

$$\sqrt{2200^2 + 1990^2 - 2(2200)(1990)cos25°}\ N$$

$$= \underline{930N}.$$



Let angle that net force makes with the wind force vector be θ. Then, by law of cosines,

$1990^2 = 2200^2 + 930^2 - 2(2200)(930)\cos\theta$

$\cos\theta = (2200^2 + 930^2 - 1990^2)/2(2200)(930)$

$= 0.426$

$\underline{\theta = 65°}$

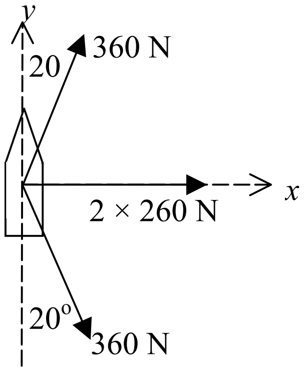
The net force vector is pointing in the direction of the longitudinal axis of the boat, with magnitude 930 N.

†5-31. Define x and y axes with the x direction perpendicular to the dock and the y direction along the dock. Resolve the two 360-N forces into x and y components. By symmetry the y components cancel. The resultant force in the x direction is

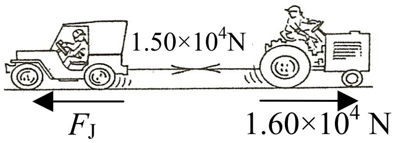
$R_x = 2 \times 260\ \ \text{N} + 2 \times (360\ \text{N})\sin 20° = 766\ \text{N}.$

The resultant expressed as a vector is

$\underline{\mathbf{R} = 766\mathbf{i} + 0\mathbf{j}\ \ \text{N}}.$



5-32. Take the x direction to point right. The net force on the tractor is $\mathbf{F}_{\text{T}} = (1.60 \times 10^4\ \text{N})\mathbf{i} - (1.50 \times 10^4\ \text{N})\mathbf{i} = (1.0 \times 10^3\ \text{N})\mathbf{i}$. (The vertical forces add to zero, so they aren't included here.)



The acceleration of the tractor is $\mathbf{a} = \dfrac{\mathbf{F}_{\text{T}}}{m_T} = \dfrac{(1.0 \times 10^3\ \text{N})\mathbf{i}}{2000\ \text{kg}}$

$= (0.50\ \text{m/s}^2)\mathbf{i}$. Because the rope connecting the tractor to the Jeep doesn't stretch or break and has negligible mass, the magnitude of the tension at the Jeep must be the same as at the tractor, and the Jeep's acceleration must be the same as the tractor's acceleration. Thus the net force on the Jeep points to the right and has a magnitude given by

$\sum \mathbf{F} = m_J\mathbf{a} = (1.50 \times 10^4\ \text{N} - F_J)\mathbf{i}$

$= (1400\ \text{kg})(0.50\ \text{m/s}^2)\mathbf{i} = (700\ \text{N})\mathbf{i}$, where we have assumed that the force on the tractor points to the left. Solving for F_J gives $F_{\text{J}} = 1.43 \times 10^4\ \text{N}$, which is the magnitude of the force. Because we assumed it points to the left, the vector is $\underline{\mathbf{F}_{\text{J}} = -(1.43 \times 10^4\ \text{N})\mathbf{i}}$.

5-33. $m = \dfrac{W}{g} = \dfrac{25\ \text{N}}{9.81\ \text{m/s}^2} = 2.6\ \text{kg}.\ W = mg = (3.5\ \text{kg})(9.81\ \text{m/s}^2) = \underline{34\ \text{N}}.$

5-34. $W_{Pluto} = mg_{Pluto} = 60\ \text{kg} \times (0.045 \times 9.81\ \text{m/s}^2) = \underline{26\ \text{N}}.$

†5-35. $m = \dfrac{W_{Earth}}{g_{Earth}} = \dfrac{750\ \text{N}}{9.81\ \text{m/s}^2} = \underline{76.5\ \text{kg}}$. Mass is an intrinsic property of the object, so its mass is 76.5 kg on Earth, Mars, and Jupiter. Its weight depends on the value of g. The calculations can be simplified using proportional reasoning:

$$W_{Mars} = mg_{Mars} = W_{Earth}\frac{g_{Mars}}{g_{Earth}} = 0.38(750\ \text{N}) = 285\ \text{N}$$

$$W_{Jupiter} = mg_{Jupiter} = W_{Earth}\frac{g_{Jupiter}}{g_{Earth}} = 2.53(750\ \text{N}) = 1.90 \times 10^3\ \text{N}$$

5-36. 1 lb = 0.4536 kg, 1 lbf = 4.4482 N. Find the weight in New York and then use proportional reasoning to find weights in Hong Kong and Quito.

$$W_{NY} = 1\ \text{lb} \times \frac{0.4536\ \text{kg}}{\text{lb}} \times 9.803\ \text{m/s}^2 \times \frac{1\ \text{lbf}}{4.4482\ \text{N}} = \underline{0.9996\ \text{lbf}}.$$

$$W_{HK} = W_{NY} \times \frac{9.788}{9.803} = \underline{0.9981\ \text{lbf}}.$$

$$W_{Q} = W_{NY} \times \frac{9.780}{9.803} = \underline{0.9973\ \text{lbf}}.$$

5-37. (a) $\Delta W = m\left(g_{Paris} - g_{SF}\right) = (0.50000\ \text{kg})\left(9.8094\ \text{m/s}^2 - 9.7996\ \text{m/s}^2\right) = 4.900 \times 10^{-3}\ \text{N}.$

$$\frac{\Delta W}{W_{Paris}} = m\left(\frac{g_{Paris} - g_{SF}}{g_{Paris}}\right) = m\left(1 - \frac{g_{SF}}{g_{Paris}}\right) = \underline{9.058 \times 10^{-3}}.$$

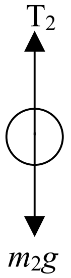
(b) The value of the gold depends on its *mass*, not its weight. Its mass doesn't change, so its value doesn't change in the move.

5-38. The chair exerts $60 \times 9.8 = \underline{588\ \text{N}}$ on the woman.

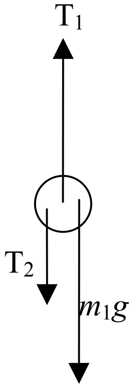
The floor exerts $(60 + 20)9.8 = \underline{784\ \text{N}}$ on the chair.

†5-39. Draw two "free–body" diagrams:

Bottom chandelier:



Top chandelier:



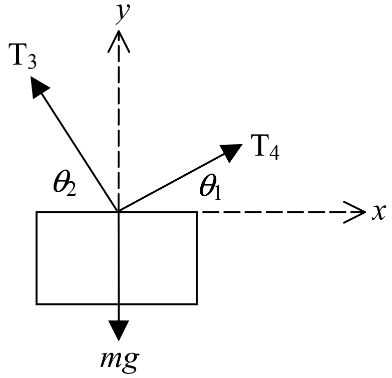
$\text{T}_2 - m_2 g = 0$

$\text{T}_2 = m_2 g = \underline{29.4\ \text{N}}$

$\text{T}_1 - \text{T}_2 - m_1 g = 0$

$\text{T}_1 = \text{T}_2 + m_1 g = m_2 g + m_1 g = \underline{128\ \text{N}}$

5-40. Call the tension in the 3-m cable T₃ and the tension in the 4–m cable T₄. The two cables form a 3–4–5 right triangle. The trig functions for the angles θ_1 and θ_2 are then easy to as figure out. Resolve the forces into components along the x and y as axes as shown and set the net force along each direction equal to zero:



$$\sum F_y = \mathrm{T}_4 \sin\theta_1 + \mathrm{T}_3 \sin\theta_2 - mg = 0$$

$$\sum F_x = \mathrm{T}_4 \cos\theta_1 - \mathrm{T}_3 \cos\theta_2 = 0$$

Rearrange:

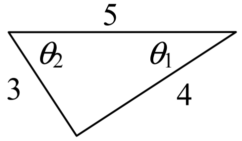
$$\mathrm{T}_4 \sin\theta_1 = mg - \mathrm{T}_3 \sin\theta_2$$

$$\mathrm{T}_4 \cos\theta_1 = \mathrm{T}_3 \cos\theta_2$$

Divide the top equation by the bottom equation and solve for T₃:

$$\tan\theta_1 = \frac{mg - \mathrm{T}_3 \sin\theta_2}{\mathrm{T}_3 \cos\theta_2}$$

$$\mathrm{T}_3 = \frac{mg}{\tan\theta_1 \cos\theta_2 + \sin\theta_2}$$

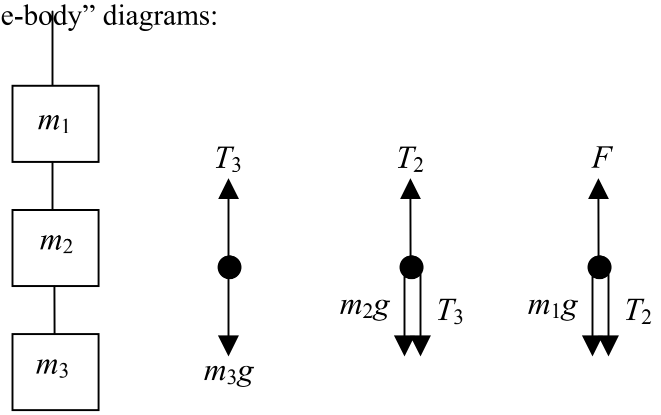


Use the trig functions: [tan θ_1 = 0.75, sin θ_2 = 0.8, cos θ_2 = 0.6] to find T₃:

$$\mathrm{T}_3 = \frac{200\ \ \mathrm{kg} \times 9.81\ \mathrm{m/s^2}}{(0.75)(0.6) + 0.8} = \underline{1.57 \times 10^3\ \mathrm{N}}.$$ Use this value and cos θ_1 = 0.8 to calculate T₄:

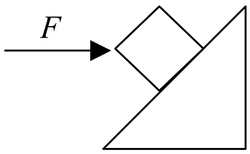
$$\mathrm{T}_4 = \frac{\mathrm{T}_3 \cos\theta_2}{\cos\theta_1} = \frac{(0.6)(1.57 \times 10^3\ \mathrm{N})}{0.8} = \underline{1.28 \times 10^3\ \mathrm{N}}.$$

†5-41. "Free-body" diagrams:

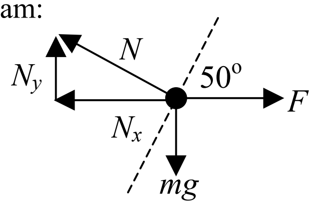


The system is described as being stationary, so it must be in equilibrium. Thus the net force on each mass must be zero. For m_3, $T_3 - m_3 g = 0 \Rightarrow T_3 = m_3 g.$ For m_2, $T_2 - T_3 - m_2 g = 0 \Rightarrow T_2 = T_3 + m_2 g = (m_2 + m_3)g.$ For m_1, $F - T_2 - m_1 g = 0 \Rightarrow$ $\underline{F = T_2 + m_1 g = (m_1 + m_2 + m_3)g.}$

5-42.

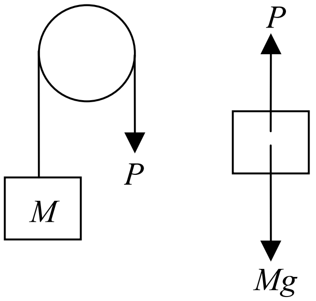


"Free-body" diagram:

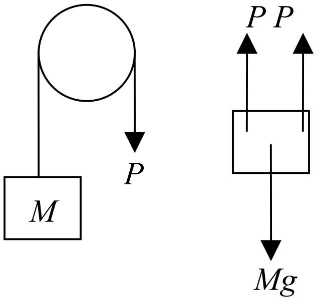


The net force on the box is zero. The x and y components of the normal force N are shown in the "free-body" diagram. $N_y - mg = 0 \Rightarrow N_y = mg = (5\text{ kg})\left(9.81\text{ m/s}^2\right) = 49.1\text{ N}$. Because N is perpendicular to the ramp and the ramp is inclined at 50°, the angle between N and N_x is 40°. Thus $N_y = N\sin 40° \Rightarrow N = \dfrac{N_y}{\sin 40°} = \dfrac{49.1\text{ N}}{\sin 40°} = 76.4\text{ N}$. To find F, set the sum of forces in the x direction equal to zero: $F - N_x = 0 \Rightarrow F = N_x = N\cos 40° = (76.4\text{ N})\cos 40° = \underline{58.5\text{ N}}.$

†5-43. Suppose another sailor pulls on the free end of the rope with a force P as shown. Then the "free-body" diagram for the sailor in the seat has two forces, and the net force on the sailor is $F_{net} = P - Mg$. The reaction from the rope acts on the puller. For the sailor to move up, P must at least be equal to Mg. If the sailor in the seat reaches over and pulls on the rope, the reaction from the rope pulls up on the sailor in the seat. Now the "free-body" diagram shows *two* upward forces on the sailor in the seat, and the net force is $F_{net} = 2P - Mg$. Now the minimum force required for the sailor to lift himself is $Mg/2$.

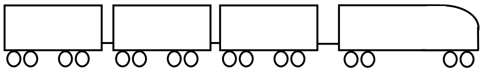


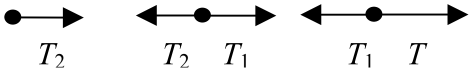
Another sailor pulls on the rope.



The sailor in the seat pulls himself up.

5-44.





In the "free-body" diagrams, $T = 12\ 000$ N. T_1 is the tension in the coupler between cars 1 and 2, and T_2 is the tension in the coupler between cars 2 and 3. All three cars have the same mass M and the same acceleration a. (The vertical forces on the cars have been ignored because they add to zero.) Writing Newton's Second Law for each car gives
$T - T_1 = Ma,\ T_1 - T_2 = Ma,\ T_2 = Ma.$

Adding the second and third equations gives $T_1 = 2Ma$. Substituting this into the first equation gives $T = 3Ma$. This means $T_1 = \frac{2}{3}T = \underline{8000\text{ N}}$. From the third equation we get $T_2 = \frac{T_1}{2} = \underline{4000\text{ N}}$.

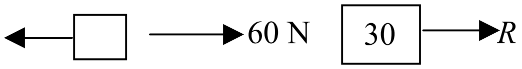
Suppose a friction force *f* acts on each car. The direction will be to the left in the diagram: $T - T_1 - f = Ma,\ T_1 - T_2 - f = Ma,\ T_2 - f = Ma.$ Subtracting the third equation from the second gives $T_1 - 2T_2 = 0$, which is the same relation we had before. Subtracting the second equation from the first gives $T - 2T_1 - T_2 = T - \frac{3}{2}T_1 = 0,$ which is the same result we had before. So adding the same friction force to each car does not change the tensions. (Our intuition would tell us that adding a constant friction force should not change the result, but it's good to demonstrate the result rigorously.)

5-45. At every point along the cable, the net force must be zero. That means the upward tension must equal the weight of the cable below that point. At the very top the upward force must be equal to the total weight of the cable, so $\underline{T = \frac{\pi d^2 l \rho g}{4}}$. At the midpoint, the tension must be equal to half the weight: $\underline{T = \frac{\pi d^2 l \rho g}{8}}$.

5-46. By Newton's Third Law, the forces the car and truck exert on each other must have equal magnitudes and opposite directions. Thus $m_{truck}a_{truck} = -m_{car}a_{car}$. Then

$$a_{car} = -\frac{m_{truck}a_{truck}}{m_{car}} = -\frac{2800\text{ kg} \times \left(-500\text{ m/s}^2\right)}{1200\text{ kg}} = \underline{1.17 \times 10^3\text{ m/s}^2}.$$ The final speed of the car is $v = a_{car}t = \left(1.17 \times 10^3\text{ m/s}^2\right)(0.20\text{ s}) = \underline{233\text{ m/s}}$.

†5-47. The 60-N force acts on a total mass of 50 kg, so $a = \frac{F}{m_{total}} = \frac{60\text{ N}}{50\text{ kg}} = \underline{1.2\text{ m/s}^2}$. To find the force each mass exerts on the other, use these "free-body" diagrams with *R* as the unknown force, assuming the 60-N force points to the right:



The vertical forces aren't shown because they add to zero. Applying Newton's Second Law to the 30-kg mass gives $R = 30a = \underline{36\text{ N}}$. The 20-kg box exerts a 36-N force to the right on the 30-kg box, and the 30-kg box exerts a 36-N force to the left on the 20 kg box. (Note: To check, note that the net force on the 20 kg box is (60 – 36) N = 24 N. This gives an acceleration of 1.2 m/s^2.)

5-48. The minimum distance corresponds to the maximum frictional force, $F = \mu_S mg = ma$ or $a = \mu_S g$

$v_0 = 90$ km/h = 25 m/s

$\left|v^2 - v_0^2\right| = 2ax = 2\,\mu_S\,gx$

$$x = \frac{v_0^2}{2\mu_s\,g} = \frac{(25)^2}{2 \times 0.8 \times 9.8} = \underline{39.9\text{m}}$$

5-49. $v_0 = \sqrt{2\mu_s\,gx}$ (see solution to question 26)

$= \sqrt{2 \times 0.8 \times 9.8 \times 290} = 67.4$ m/s = $\underline{243\,\text{km/h}}$

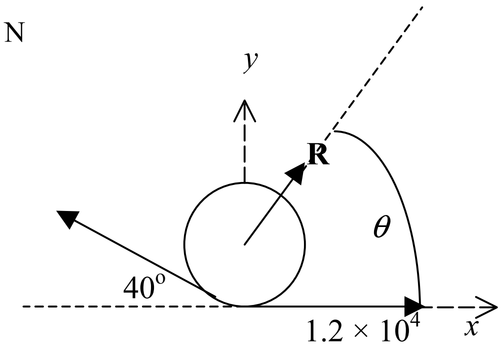
5-50. Find the x and y components of the resultant force **R**:

$R_x = 1.2 \times 10^4\ \text{N} - \left(1.2 \times 10^4\ \text{N}\right)\cos 40° = 2.81 \times 10^3\ \text{N}$

$R_y = \left(1.2 \times 10^4\ \text{N}\right)\sin 40° = 7.71 \times 10^3\ \text{N}$

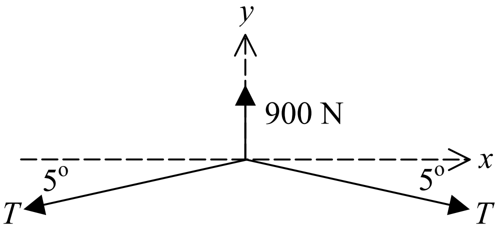
$\mathbf{R} = (2.81 \times 10^3\ \text{N})\mathbf{i} + (7.71 \times 10^3\ \text{N})\mathbf{j}$

$\left|\mathbf{R}\right| = \sqrt{R_x^2 + R_y^2} = \underline{8.2 \times 10^3\ \text{N}}\quad \theta = \tan^{-1}\dfrac{R_y}{R_x} = \underline{70°}$



5-51. The net force on the point where the rope is being pushed must be zero. By symmetry the x components of the tension cancel. The sum of the y components of the forces must also add to zero:

$\sum F_y = 900\ \text{N} - 2T\sin 5° = 0 \Rightarrow T = \dfrac{900\ \ \text{N}}{2\sin 5°} = \underline{5.16 \times 10^3\ \text{N}}$

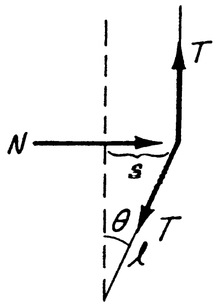


5-52. (a) Forces are as shown on diagram. For forces to balance, $T\sin\theta = \underline{N}$ but $\sin\theta = s/l$, so that $\text{N} = Ts/l \geq \underline{T = Nl/s.}$

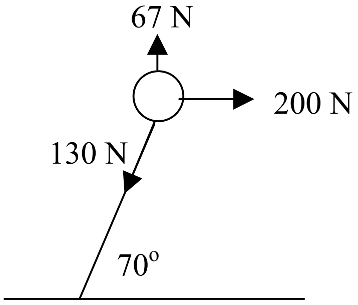
(b) Using formula

$T = 150\ \text{N} \times 1.5\ m/0.02\ m$

$= \underline{1.1 \times 10^4\,\text{N}}$



†5-53. The net force is the vector sum of the force exerted by the wind plus the tension in the string. (The weight of the balloon is assumed to be much less than the other forces acting and can be neglected.) Take the +*y* direction to point up and the +*x* direction to point right. Then



$$F_{net,x} = 200 \text{ N} - (130 \text{ N})\cos 70^\circ = 156 \text{ N}$$

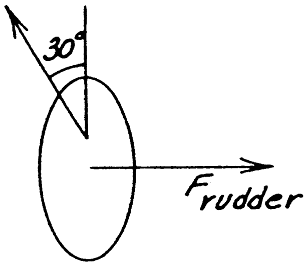
$$F_{net,y} = 67 \text{ N} - (130 \text{ N})\sin 70^\circ = -55.2 \text{ N}$$

$$|\mathbf{F}_{net}| = \sqrt{R_x^2 + R_y^2} = \underline{165 \text{ N}}$$

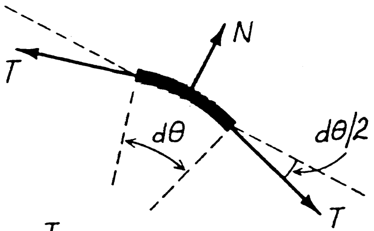
$$\theta = \tan^{-1}\frac{R_y}{R_x} = \underline{-19.4^\circ} \text{ (19.4° \textit{below} horizontal, or +}x\text{ direction)}$$

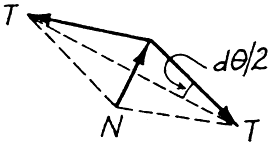
(A dynamics note: because the net force is not zero, the balloon is not in equilibrium at the instant described in this problem.)

5-54. Because there cannot be a net force in direction perpendicular to bank, the components of force in this direction must cancel. Therefore, the component in this direction of force from horse = 300 sin 30° = 150 N.
Thus, the transverse force of the rudder is 150 N, , pointing away from the bank.



5-55. The first diagram shows the forces on a small segment of rope. From the second diagram we see that balance of these forces requires





$$2T\sin\left(\frac{d\theta}{2}\right) = dN,$$

or because $d\theta$ is small, $2T\,\dfrac{d\theta}{2} \cong dN$

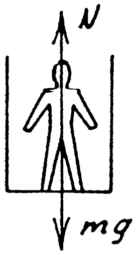
$$\underline{dN = Td\theta}.$$

The vertical component of this force is = cos θ $Td\theta$, where the angle θ is measured from the vertical. Integrate this from $\theta = -90^\circ$ to $\theta = 90^\circ$.

$$F = \int_{-90^\circ}^{90^\circ} T\cos\theta\, d\theta = Y\int \cos\theta d\theta$$

$$= T\sin\theta\Big|_{-90^\circ}^{90^\circ} \qquad \underline{= 2T}$$

5-56. N = normal force. Then net upward force = $N - mg$
$N - mg = ma \Rightarrow N = ma + mg = m(a + g)$
$N = 80\text{ kg}(9.8 + 1.8)\text{ m/s}^2 = 928\text{ N}$
Normal force exceeds weight by
$N = \text{mg} = 80(1.8)N = 144\text{ N}$



5-57. Deceleration $a = \dfrac{v_i^2 - v_f^2}{2s} = \dfrac{25}{2 \times 1} = 12.5\text{m/s}^2$

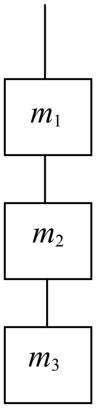
The force exerted by the ground on the feet is N, where $N - mg = ma$
$N = m(g + a) = 80(9.8 + 12.5) = 1784\text{ N}$.

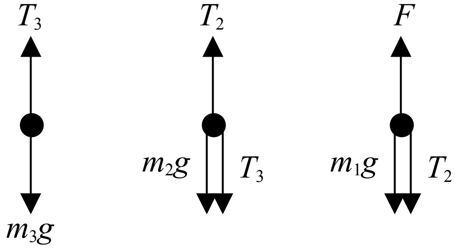
5-58. From Example 10, $a_1 = \dfrac{m_2 - m_1}{m_1 + m_2}g$, where m_1 is the mass of the elevator cage and m_2 is the mass of the counterweight. Here $m_1 = 1280$ kg, the mass of the empty cage plus the mass of four people at 70 kg each. $a = \dfrac{1100\ \text{kg} - 1280\ \text{kg}}{2380\ \text{kg}} \times 9.81\text{ m/s}^2 = -0.742\text{ m/s}^2$. The – sign means the car is moving *down* because in the example the positive direction for vectors was chosen to be up. To find the speed, use $v^2 = v_0^2 + 2ax$ with caution. a and x are both vector quantities, and their algebraic signs must agree. In this problem, we already know that the car is accelerating downward. Because it began moving from rest, its displacement x is also downward and would be represented by a negative number. Thus the product ax is *positive*, giving

$$v = \sqrt{2ax} = \sqrt{2 \times \left(-0.742\text{ m/s}^2\right) \times (-10\text{ m})} = 3.85\text{ m/s.}$$

†5-59. A diagram and three "free-body" diagrams are shown. Write Newton's Second Law for each of the three masses:

$$F - m_1 g - T_2 = m_1 a_1$$
$$T_2 - m_2 g - T_3 = m_2 a_2$$
$$T_3 - m_3 g_2 = m_3 a_3$$





All three masses must have the same acceleration: $a_1 = a_2 = a_3$, which we'll just call a. To find a, add all three equations together. Then T_2 and T_3 cancel, giving

$$F - (m_1 + m_2 + m_3)g = (m_1 + m_2 + m_3)a$$

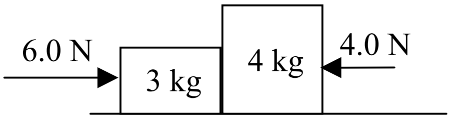
$$\Rightarrow a = \frac{F - (m_1 + m_2 + m_3)g}{m_1 + m_2 + m_3}.$$

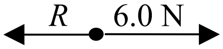
Then the tension in the first cable is F, and the tensions in the second and third cables are

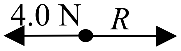
$$T_1 = F - m_1(g + a) = F\left(\frac{m_2 + m_3}{m_1 + m_2 + m_3}\right)$$ and

$$T_2 = m_3(g + a) = F\left(\frac{m_3}{m_1 + m_2 + m_3}\right).$$

5-60.







A sketch shows the two "free-body" diagrams with the force each box exerts on the other called R. Write Newton's Second Law for each box, recognizing that both boxes must have the same acceleration and taking the positive direction to point to the right:

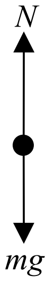
$$6.0 - R = 3a$$

$$R - 4.0 = 4a$$

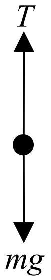
Add the two equations to find a: $2.0 = 7a \Rightarrow a = \frac{2}{7}\frac{\text{m}}{\text{s}^2} = 0.29\ \text{m/s}^2$. (The acceleration points to the right.) Now we can solve either of the individual equations to find R:

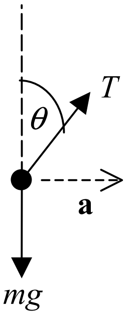
$R = 4a + 4.0\quad \text{N} = \frac{36}{7}\text{N} = \underline{5.1\ \text{N}}$. The 3-kg mass exerts a force of 5.1 N to the right on the 4-kg mass, and the 4-kg mass exerts a force of 5.1 N to the left on the 3-kg mass.

†5-61. The reading on the scale is the normal force exerted by the scale. The net force on the passenger is $N - mg = ma \Rightarrow N = mg + ma$, choosing up to be the positive direction for vectors. The man's mass is 220 lbm = 99.8 kg, and his weight is mg = 220 lbf = 979 N. If $a = 1.6\ \text{m/s}^2$, then $N = (979\ \text{N} + 99.8\ \text{kg} \times 1.6\ \text{m/s}^2) = \underline{1139\ \text{N} = 256\ \text{lb}}$. If the elevator has a downward acceleration, then $a = -1.6\ \text{m/s}^2$, and $\underline{N = 819\ \text{N} = 184\ \text{lb}}$.



5-62. $T - mg = ma \Rightarrow a = m(a + g) = 9.5\ \text{kg}\left(1.9\ \text{m/s}^2 + 9.81\ \text{m/s}^2\right) = \underline{111\ \text{N}}$.





†5-63. A "free-body" diagram is shown for one of the dice. From the diagram,

$T\cos\theta - mg = 0,\ T\sin\theta = ma$

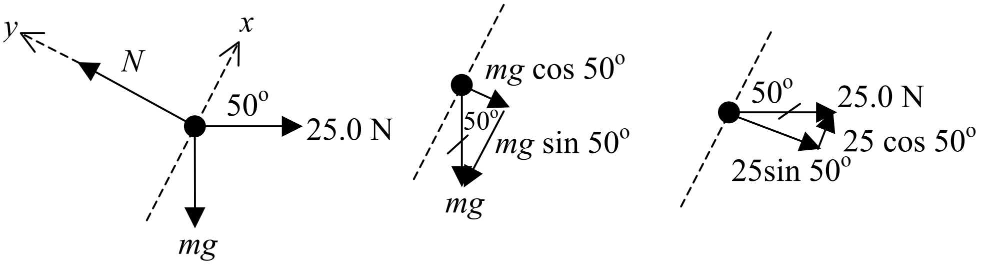
where the positive horizontal direction is assumed to point to the right, and the positive vertical direction is up. Dividing the bottom equation by the top equation gives $\tan\theta = \frac{a}{g}$, so

$\theta = \tan^{-1}\left(\frac{2.5\ \text{m/s}^2}{9.81\ \text{m/s}^2}\right) = 14.3°$. The final result = $\underline{14^{\text{o}}}$. The tension in

the string for each die is $T = \frac{mg}{\cos\theta} = \frac{0.025\ \text{kg} \times 9.81\ \text{m/s}^2}{\cos 14.3°} =$

$\underline{0.25\ \text{N}}$.

5-64.



Three diagrams are given. One is a "free-body" diagram showing the three forces acting on the box along with definitions of the x and y directions pointing up the incline and perpendicular to the incline. The other two show resolution of the vertical weight mg and the horizontal 25 N force into components along the x and y directions. Now write Newton's Second Law for the x direction: $25\cos 50° - mg\sin 50° = ma$. (The sum of forces in the y direction is zero because there is no motion perpendicular to the incline.) The acceleration is

$$a = \frac{(25.0\ \ \text{N})\cos 50° - (3.50\ \ \text{kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)\sin 50°}{3.50\ \ \text{kg}} = \underline{-2.92\frac{\text{m}}{\text{s}^2}}.$$

The – sign means the mass is sliding *down* the incline—the 25-N force is not large enough to cause it to slide up.

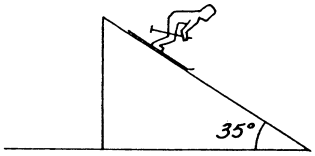
5-65. Force = $mg\sin\theta$

$a = \frac{F}{m} = g\sin\theta = 9.8 \times \frac{1}{\sqrt{26}} = \underline{1.9\text{m/s}^2}$

Speed after 50 m; use $v^2 - v_0^2 = 2a(x - x_0)$

$v = \sqrt{2 \times 1.9 \times 50}\ \text{m/s} = \underline{14\,\text{m/s}}$

5-66. (a) See drawing of skier on the right.



(b) $mg = 75 \times 9.8\ N = \underline{735\,\text{N}}$

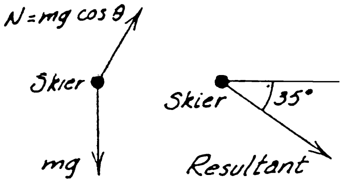
Normal force $= mg \cos\theta = 735 \cos 35° = \underline{602\,\text{N}}$

Magnitude of resultant $= mg \sin\theta$

$= 735 \sin 35° = \underline{422\,\text{N}}$

(c) $$a = \frac{F}{m} = \frac{75 \times 9.8 \times \sin 35°}{75}\ \text{m/s}^2$$

$= 9.8 \sin 35°\ \text{m/s}^2 = \underline{5.62\,\text{m/s}^2}$



5-67. $a = g \sin\theta = 9.8 \times \sin 30°\ \text{m/s}^2 = 4.9\ \text{m/s}^2$

90 km/hr = 25 m/s

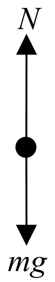
$v^2 - v_0^2 = 2a(x - x_0)$

$$x - x_0 = \frac{25^2}{2(4.9)}\ \text{m} = \underline{64\,\text{m}}$$

$$\text{Time taken: } t = \frac{v - v_0}{a} = \frac{25\,\text{m/s}}{4.9\,\text{m/s}^2} = \underline{5.1\,\text{s}}$$

5-68. N = the force the shoulder exerts on the backpack, which is equal and opposite to the force the backpack exerts on the shoulder. $N - mg = ma \Rightarrow N = m(a + g)$.

$$N = (20\ \ \text{kg})\left(2.0\frac{\text{m}}{\text{s}^2} + 9.8\frac{\text{m}}{\text{s}^2}\right) = 236\ \text{N}.$$ The force exerted by the backpack on the shoulder is $\underline{236\ \text{N down}}$.



5-69. $\sum F_x = 0 = T \sin\theta - N$ (i)

$\sum F_y = 0 = T \cos\theta = mg$ (ii)

Dividing (i) by (ii) we get

$\tan\theta = N/mg$

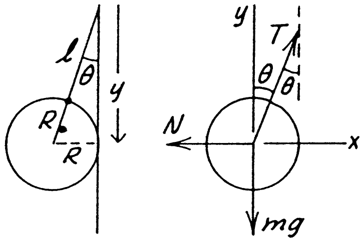
$N = mg \tan\theta$

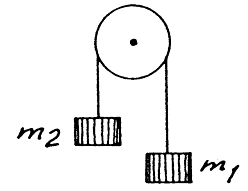
but $R^2 + y^2 = (e + R)^2 \Rightarrow y^2$

$= e^2 + 2eR = e(e + 2R)$

$$\tan\theta = \frac{R}{\sqrt{e(e + 2R)}}$$

$$\underline{N = \frac{mgR}{\sqrt{e(e + 2R)}}}$$ (Note that $N \to 0$ as $e \to \infty$)





5-70. By the equation in example 10,

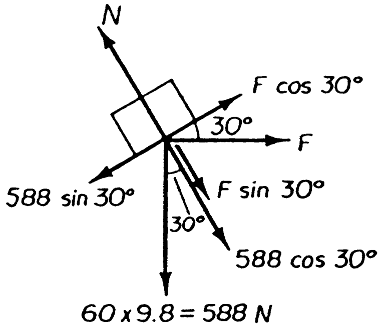
$a = \left(\dfrac{m_2 m_1}{m_1 + m_2}\right) g$ (where g is the unknown acceleration due to gravity)

$= \dfrac{402.0 - 400.0}{400.0 + 402.0} \times g = 2.4938 \times 10^{-3} \times g$

But $x - x_0 = v_0 t + \dfrac{1}{2} a t^2$

$$a = \frac{2[(x - x_0) - v_0 t]}{t^2} = \frac{2(0.50\,\text{m})}{6.42}\,\text{s}^2 = 0.0244\ \text{m/s}^2 = 2.4938 \times 10^{-3} \times g$$

$$g = \frac{0.0244}{2.4938 \times 10^{-3}}\ \text{m/s}^2 = \underline{9.79\,\text{m}/\text{s}^2}$$

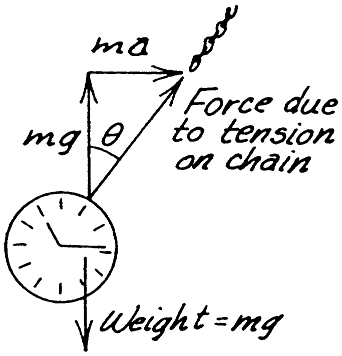


5-71. $F \cos 30 - 588 \sin 30° = 0$

$F = 588 \tan 30° = \underline{339.5\,\text{N}}$

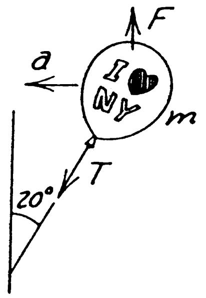
$N - F \sin 30° - 588 \cos 30° = 0$

$N = F \sin 30° + 588 \cos 30° = \underline{679\,\text{N}}$



5-72. Since the watch is at rest in the frame of the airplane, it is accelerating at 1.2 m/s with respect to the inertial frame (i.e., earth). This force is transmitted to watch via chain. The components of this force are as shown in the diagram. The angle θ that the chain makes with the vertical is

$\tan^{-1}(a/g) = \tan^{-1}(1.2/9.8) = \underline{7.0°}$



5-73. (a) Inclined forwards.

(b) The component of force acting in the horizontal direction is $T \sin 20°$ where T is tension in string. Therefore $T \sin 20° = ma$

$T \cos 20° = F$ where F is the net force on the balloon in the vertical direction and is the difference in the buoyant force and the weight of the helium. The mass of the fabric is assumed negligible.

This is equal to $V(\rho_a - \rho_=)g$, where V = volume of balloon; ρ_a, ρ_h are densities of air and helium respectively.

$T \cos 20° = V(\rho_a - \rho_h)g$ (i)

$T \sin 20° = ma = v\rho_h a$ (ii)

(ii) + (i) gives $\tan 20° = \dfrac{V\rho_h a}{V(\rho_a - \rho_h)g} = \dfrac{\rho_h}{(\rho_a - \rho_h)g} a$

$a = \tan 20° \left(\dfrac{\rho_a - \rho_h}{\rho_h}\right) g$

$\rho_a = 1.293 \text{ kg/m}^3$

$\rho_h = 0.1785 \text{ kg/m}^3$

$a = \tan 20° \left(\dfrac{1.2930. - 0.1785}{0.1785}\right) 9.8 \text{ m/s}^2 = \underline{22.3 m/\text{s}^2}$

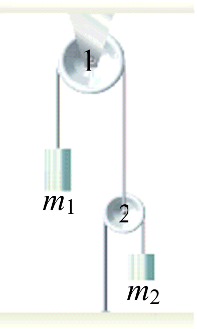
5-74. Three "free-body" diagrams are shown beside the figure. Note that a "free-body" diagram is included for pulley 2. Write Newton's Second Law for each diagram:

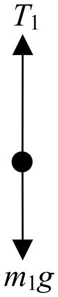
$T_1 - m_1 g = m_1 a_1$

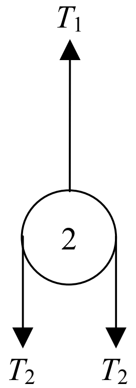
$T_1 - 2T_2 = 0$

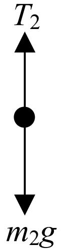
$T_2 - m_2 g = m_2 a_2$

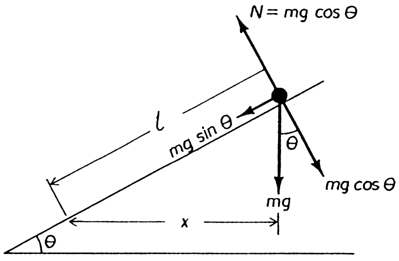
The second equation is tricky. It describes the acceleration of pulley 2, but because we assume the pulley is massless, it says the sum of forces must be zero. To solve the equations, we must figure out the relation between the accelerations a_1 and a_2. If mass m_1 falls a distance h, then pulley 2 will be pulled up the same distance. Because one end of the string over pulley 2 is fixed, m_2 will be raised twice as far, $2h$. Thus the magnitude of a_2 is twice the magnitude of a_1. We also see that if m_1 moves down, m_2 moves up. Thus $a_2 = -2a_1$. Making these substitutions in the third equation gives $T_2 = m_2 g - 2m_2 a_1$. Substituting $T_1 = 2T_2$ from the second equation in the first equation gives $\underline{a_1 = \dfrac{2m_2 - m_1}{m_1 + 4m_2} g}$. The acceleration of pulley 2 is $\underline{-a_1}$, and the acceleration of m_2 is $\underline{-2_1}$.











5-75. Along the incline $mg \sin\theta = ma$,

$a = g \sin\theta$

distance, l moved along the incline in time t

$$l = \frac{1}{2} g \sin\theta \bullet t^2$$

horizontal distance $x = l \cos\theta$

$$= \frac{1}{2} g \sin\theta \cos\theta\, t^2$$

$$t = \sqrt{\frac{2x}{g \sin\theta \cos\theta}}$$

$$\frac{dt}{d\theta} = 0 = \sqrt{\frac{2x}{g}}\, \frac{1/2(\cos^2\theta - \sin^2\theta)}{(\sin\theta\ \cos\theta)^{3/2}} \quad \text{if } \theta = \tan^{-1}(l)$$

$$= \underline{45°}$$

Minimum time, $t_{\min} = \sqrt{\frac{2x}{g \sin 45° \cos 45°}} = \underline{2\sqrt{\frac{x}{g}}}$

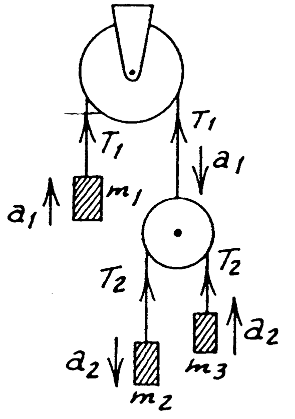
5-76. The equation of motion of each mass is

$m_1 a_1 = T_1 - m_1 g$ (i)

$m_3(a_2 - a_1) = T_2 - m_3 g$ (ii)

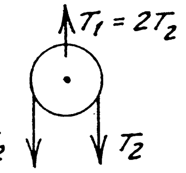
$m_2(-a_1 - a_2) = T_2 - m_3 g$ (iii)

$2T_2 = T_1$ (iv)



The extra a_1 term in equations (ii) and (iii) occur because a_2 is the acceleration of the masses m_2 and m_3 with respect to the small pulley. *But* the small pulley is also accelerating with respect to the inertial frame downwards at a rate of a_2!

(iv) comes about because the pulley is massless, hence the net force on the pulley must be zero.



(ii) – (iii) gives: $m_3(a_2 - a_1) + m_2(a_1 + a_2) = (m_2 - m_3)g$

Substituting (iv) into (i) and (i) – 2(ii) gives:

$m_1 a_1 - 2m_3(a_2 - a_1) = -m_1 g + 2m_3 g$

or $(m_1 + 2m_3)a_1 - 2m_3 a_2 = (2m_3 - m_1)g$ (v)

From above: $(m_2 - m_3)a_1 + (m_2 + m_3)a_2 = (m_3 - m_3)g$ (vi)

From this:

$$a_1 = \left[\frac{(4m_2 m_3 - m_1 m_2 - m_1 m_3)}{(m_1 m_2 + 4m_2 m_3 + m_1 m_3)}\right] g$$

$$a_2 = \left[\frac{2m_1(m_2 - m_3)}{(m_1 m_2 + 4m_2 m_3 + m_1 m_3)}\right] g$$

a_1 is acceleration of mass m_1 (upwards)

Acceleration of m_2 is (relative to fixed frame)

$$\underline{a_1 + a_2 = \left[\frac{(4m_2m_3 - m_1m_2 - 3m_1m_3)}{(m_1m_2 + 4m_2m_3 + m_1m_3)}\right] g\ (down)}$$

Acceleration of m_3 is (relative to fixed frame)

$$\underline{a_2 - a_1 = \left[\frac{(3m_1m_2 - m_1m_3 - 4m_2m_3)}{(m_1m_2 + 4m_2m_3 + m_1m_3)}\right] g\quad (up)}$$

From (i), $T_1 = m_1(a_1 + g) = \underline{\left[\frac{m_1(8m_2m_3)}{(m_1m_2 + 4m_2m_3 + m_1m_3)}\right]} g$

$$T_2 = \underline{\left[\frac{4m_1m_2m_3}{(m_1m_2 + 4m_2m_3 + m_1m_3)}\right]} g$$

5-77. From Example 10, $a = \dfrac{m_2 - m_1}{m_1 + m_2} g$. If the left end of the chain is a distance x above its starting point, then $m_1 = \dfrac{m}{l}\left(\dfrac{l}{2} - x\right)$ and $m_2 = \dfrac{m}{l}\left(\dfrac{l}{2} + x\right)$. The total mass is $m_1 + m_2 = m$. Substituting these into the equation for a gives $a = \dfrac{2g}{l}x$. To find the equation for $x(t)$, use the derivative definition of a: $\dfrac{d^2x}{dt^2} = \dfrac{2g}{l}x$. According to the hint, the solution to this is $x(t) = Ae^{\sqrt{\frac{2g}{l}}t}$. To find A, use the fact that at $t = 0$, $x = x_0 \Rightarrow \underline{x(t) = x_0e^{\sqrt{\frac{2g}{l}}t}}$.

5-78. The forces on the car and truck must have equal magnitudes, so $m_{car}\left|a_{car}\right| = m_{truck}\left|a_{truck}\right|$. Thus

$$m_{car} = \frac{m_{truck}\left|a_{truck}\right|}{\left|a_{car}\right|} = \frac{(2000\quad \text{kg})\left(1.2\ \text{m/s}^2\right)}{2.5\ \text{m/s}^2} = \underline{960\,\text{kg}}.$$

5-79. $m = 3400\text{t} = 3.4 \times 10^6\ \text{kg}$

$a = F/m = 270\ \text{N}/3.4 \times 10^6\ \text{kg} = \underline{7.9 \times 10^{-5}\,\text{m/s}^2}$

Then $x - x_0 = v_0t + \dfrac{1}{2}at^2 = 0 + \dfrac{1}{2}(7.9 \times 10^5\,\text{m/s}^2) \times (60\ \text{s})^2 = \underline{0.14\,\text{m}}$

5-80. (a) $\underline{a = \dfrac{dv}{dt} = \dfrac{d}{dt}\left(655.9 - 61.14t + 3.260t^2\right) = -61.14 + 6.520t.}$

(b) $\underline{F = ma = (45.36\quad \text{kg})\left(-61.14 + 6.520t\right) = -2773 + 295.7t.}$

The equation for v predicts that at some time the velocity would change sign, which implies that the projectile would reverse its motion and start speeding up. Of course this is not what would happen in the real world. Eventually the horizontal velocity would reach zero and the projectile would stop moving horizontally—its velocity will not begin to increase in the opposite direction. So we might expect that when the speed becomes very small, the equations in this problem will no longer accurately describe the motion of the projectile.

†5-81. $\mathbf{F}_{total} = \mathbf{F}_1 + \mathbf{F}_2 = (2-4)\mathbf{i} + (-5+8)\mathbf{j} + (3+1)\mathbf{k} = \underline{-4\mathbf{i} + 3\mathbf{j} + 4\mathbf{k}\ \text{N}}.$

$$\underline{\mathbf{a} = \frac{\mathbf{F}_{total}}{m} = \frac{-4\mathbf{i} + 3\mathbf{j} + 4\mathbf{k}\ \text{N}}{6.0\ \text{kg}} = -\frac{2}{3}\mathbf{i} + \frac{1}{2}\mathbf{j} + \frac{2}{3}\mathbf{k}\ \text{m/s}^2} = \underline{-0.67\mathbf{i} + 0.50\mathbf{j} + 0.67\mathbf{k}\quad \text{m/s}^2.}$$

$$\underline{|\mathbf{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} = \sqrt{\left(\frac{2}{3}\right)^2 + \left(\frac{1}{2}\right)^2 + \left(\frac{2}{3}\right)^2} = \underline{1.1\,\text{m/s}^2}.}$$

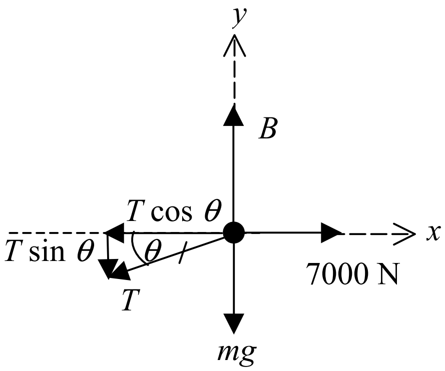
5-82. (a) Force on diver = $ma = 75\ \text{kg} \times 9.81\ \text{m/s}^2 = \underline{736\,\text{N}}$.

By the third law, the force on the Earth is 736 N

(b) Acceleration of diver = $\underline{9.8\,\text{m/s}^2}$ = 735 N/mass of Earth

= 735 N/5.98 × 10^{24} kg $\approx \underline{1.3 \times 10^{-22}\,\text{m/s}^2}$.

†5-83. (a) Represent the boat as a point mass. The water exerts an upward force with magnitude B on the boat. The tension T is shown resolved into x and y components. The angle θ is found from the fact that the rope is 50 m long and the depth of the water is 10 m: $\theta = \sin^{-1}\left(\frac{10\ \text{m}}{50\ \text{m}}\right) = 11.5°$.



(b) The boat is in equilibrium so the sum of all the forces on the boat must be zero. The sum of x components will give the tension T:

$$7000\ \text{N} - T\cos\theta = 0 \Rightarrow T = \frac{7000\ \text{N}}{\cos 11.5°} = \underline{7.14 \times 10^3\ \text{N}}.$$

(c) To find B, use the sum of the y components: $B - mg - T\sin\theta = 0$

$$\Rightarrow B = mg + T\sin\theta = (2500\ \text{kg})\left(9.81\ \text{m/s}^2\right) + \left(7.14 \times 10^3\ \text{N}\right)(\sin 11.5°) = \underline{2.59 \times 10^4\ \text{N}}.$$

Vector note: $\mathbf{B} = (2.59 \times 10^4\ \text{N})\mathbf{j}$.

5-84. (a) In the diagram, the x and y components of the 80-N force are shown.

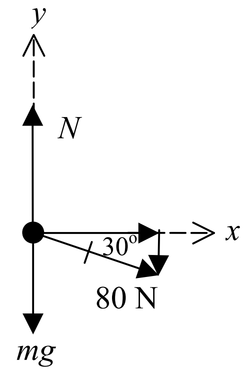
(b) In the x direction, there is only one force acting.

$F_{net,x} = \sum F_x = (80\ N)\cos 30° = ma_x$, which gives

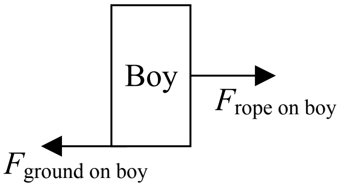
$a_x = \frac{(80\,\text{N})\cos 30°}{25\,\text{kg}} = 2.77\text{m/s}^2$. Final answer = $\underline{2.8\ \text{m/s}^2}$.

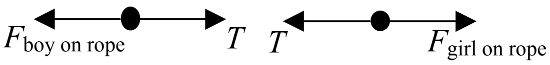
(c) There is no motion in the y direction, so $\sum F_y = 0$. This will give the normal force N: $N - mg - (80\ N)\sin 30° = 0 \Rightarrow$

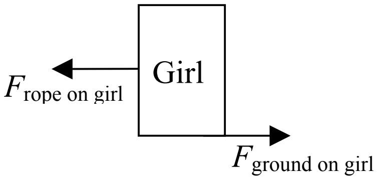
$N = (25\ \text{kg})\left(9.81\ \text{m/s}^2\right) + (80\ \text{N})(\sin 30°) = \underline{285\ \text{N}}$.



†5-85. (a) Represent each child by a block, and represent each end of the rope by points between them. Only the horizontal forces are shown. The vertical weight of each child and the vertical normal force exerted by the ground on each child have been omitted from the diagrams.







(b) By Newton's Third Law, $\left|F_{\text{rope on boy}}\right| = \left|F_{\text{boy on rope}}\right|$. Because $F_{\text{boy on rope}} = 250$ N, the magnitude of $F_{\text{rope on boy}} = 250$ N. The boy doesn't move, so the net horizontal force on him must be zero, and that means the magnitude of $F_{\text{ground on boy}} = \underline{250\text{ N}}$. By similar reasoning, the magnitude of $F_{\text{ground on girl}} = \underline{250\text{ N}}$.

(c) The net horizontal force on the rope must be zero, so $T = F_{\text{boy on rope}} = \underline{250\text{ N}}$.

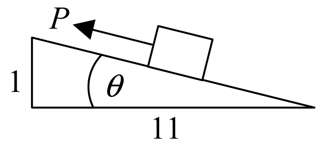
(d) Nothing changes except the origin of the force on the girl's end of the rope. Suppose the rope passed through a hole in a wall so the boy couldn't see what was at the other end. He would not be able to tell whether there was a person at the other end or if the end was tied to something immovable.

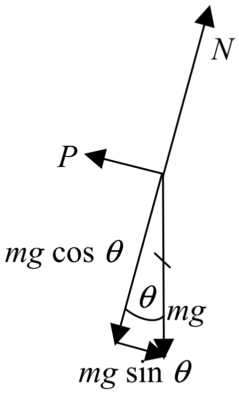
5-86. Total mass of the 250 cars is $(250 \times 64 \times 1000)\text{kg} = 1.6 \times 10^7$ kg.

The tension on the coupling between locomotive and first car = force that pulls all the cars = mass of 250 cars × accel. = $1.6 \times 10^7 \text{ kg} \times 0.043 \text{ m/s}^2 = \underline{6.9 \times 10^5\text{ N}}$.

Similarly, tension on coupling on last car = force accelerating last car = mass of 1 car × accel. = $64000 \text{ kg} \times 0.043 \text{ m/s}^2 = \underline{2.8 \times 10^3\text{ N}}$.

†5-87.



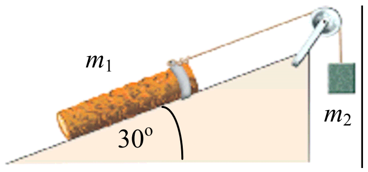


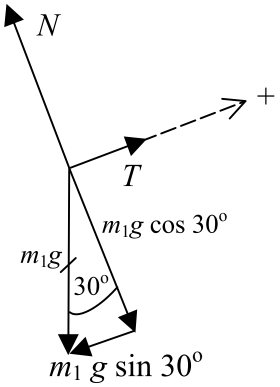
(a) A sketch is shown, and the "free-body" diagram is shown on the right. The weight of the boxcar has been resolved into components along the incline and normal to it. The angle θ can be found from the slope: $\theta = \tan^{-1}\dfrac{1}{11} = 5.19°$.

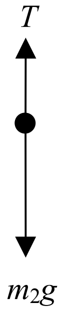
(b) For the boxcar to move at constant speed, its acceleration along the incline must be zero. Thus the sum of forces along the incline must be zero: $P - mg\sin\theta = 0$, from which we get $P = mg\sin\theta = (20 \times 10^3 \text{ kg})\left(9.81 \text{ m/s}^2\right)(\sin 5.19°) = \underline{1.8 \times 10^4\text{ N}}$. Vector note: As shown in the diagram, $\mathbf{P} = 1.8 \times 10^4$ N up the incline.

(c) In the absence of any friction forces, it makes no difference whether the car is moving at constant velocity up the incline or down the incline. The force required is 1.8×10^4 N up the incline in either case.

5-88.





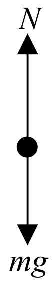


(a) "Free-body" diagrams are shown for the log (m_1) and the counterweight (m_2). The weight m_1g of the log has been resolved into components along and normal to the incline. The accelerations of the two masses must have equal magnitudes. Following Example 11, if we choose the positive direction for components along the incline to point right in the expected direction of motion, and choose the positive direction for the vectors associated with m_2 to point up, then when m_1 is accelerating in its positive direction, m_2 is accelerating in its negative direction. If the acceleration of m_1 is represented by a, the acceleration of m_2 must be $-a$. Write Newton's Second Law for the forces along the incline that act on the log and for the forces that act on the counterweight: $T - m_1g\sin 30° = m_1a$, $T - m_2g = -m_2a$. Subtract the second equation from the first to get an equation for a:

$$a = \frac{m_2 - m_1\sin 30°}{m_1 + m_2}g = \frac{300\text{ kg} - (500\text{ kg})(\sin 30°)}{500\text{ kg} + 300\text{ kg}}\left(9.81\text{ m/s}^2\right) = \underline{0.613\text{ m/s}^2}.$$

(b) The minimum value for m_2 would be one for which the acceleration would be nearly zero. This would give $T = m_2g$, which means $m_2 - m_1\sin 30° = 0$, or $m_2 = (500\text{ kg})(\sin 30°) = 250\text{ kg}$.

†5-89. The scale reading is equal to the normal force exerted on the woman by the scale. Newton's Second Law says $\sum F = N - mg = ma$, where m is the woman's mass (60 kg). The scale reading is $N = m(g + a)$. Choose the positive direction to be up.



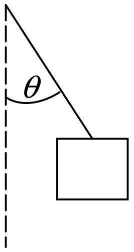
(a)At rest $\Rightarrow a = 0 \Rightarrow N = mg = (60\text{ kg})(9.81\text{ m/s}^2) = \underline{589\text{ N}}$

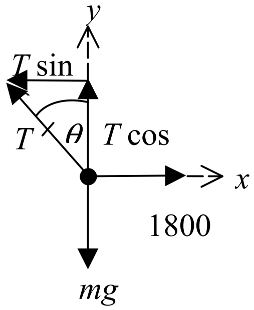
(b)Accelerating up $\Rightarrow N = (60\text{ kg})\left(9.81\text{ m/s}^2 + 1.8\text{ m/s}^2\right) = \underline{697\text{ N}}$.

(c)Constant velocity $\Rightarrow a = 0 \Rightarrow N = mg = (60\text{ kg})(9.81\text{ m/s}^2) = \underline{589\text{ N}}$.

(d)Free fall $\Rightarrow a = -g \Rightarrow N = \underline{0\text{ N}}$.

5-90. The "free-body" diagram is shown beside the sketch of the system. The tension T is resolved into x and y components. The crate is in equilibrium, so the sum of forces on it is zero.





$$F_{net,x} = \sum F_x = 1800\text{ N} - T\sin\theta = 0$$

$$F_{net,y} = \sum F_y = T\cos\theta - mg = 0$$

Rearrange:

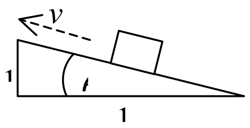
$$T\sin\theta = 1800 \quad \text{N}$$

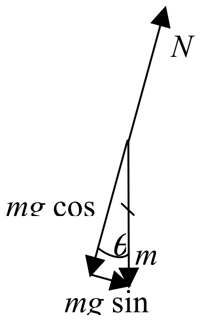
$$T\cos\theta = mg$$

Divide the first equation by the second:

$$\tan\theta = \frac{1800 \quad \text{N}}{mg} \Rightarrow \theta = \tan^{-1}\left[\frac{1800\text{ N}}{(2000\text{ kg})\left(9.81\text{ m/s}^2\right)}\right] = \underline{5.24°}.$$

†5-91. (a) A sketch and "free-body" diagram are shown with the initial velocity of the car shown in the sketch. Choose the $+x$ direction to point leftward up the incline in the direction of the original motion. The weight of the car has its x component pointing in the $-x$ direction. The sum of forces normal to the incline is zero, and there is only one force along the incline: $F_{net,x} = \sum F_x = -mg\sin\theta = ma_x$. The angle θ is found from the slope: $\theta = \tan^{-1}\frac{1}{10} = 5.71°$.





The acceleration is $a_x = -g\sin\theta = -\left(9.81\text{ m/s}^2\right)\sin 5.71° = \underline{-0.976\text{ m/s}^2}$. The – sign means the acceleration points down the incline, opposite the direction of the car's initial velocity. In non–technical language, this is the car's "deceleration."

(b) We can use $v^2 = v_0^2 + 2a_x x$, where $v = 0$ and $v_0 = 50\frac{\text{km}}{\text{h}} = 13.9\frac{\text{m}}{\text{s}}$. Solving for x gives

$$x = -\frac{v_0^2}{2a_x} = -\frac{(13.9\text{ m/s})^2}{2\left(-0.976\text{ m/s}^2\right)} = \underline{99.0\text{ m}}.$$

(c) Even when the car momentarily comes to rest and then begins to roll back down the incline, it continues to have an acceleration $a_x = -0.976\frac{\text{m}}{\text{s}^2}$. To find its speed when it gets back to its starting point, we can again use $v^2 = v_0^2 + 2a_x x$, but caution must be used in dealing with the vector quantities in the equation. Now $v_0 = 0$, and both a_x and x point *down* the incline and must be entered as negative quantities in the equation. We get $v = \sqrt{2a_x x} = \sqrt{2\left(-0.976\text{ m/s}^2\right)(-99.0\ m)} = \underline{13.9\text{ m/s}}$. (This is the car's *speed*. Its *velocity* is $-(13.9\text{ m/s})\mathbf{i}$ because it is now moving *down* the incline.)

5-92. (a) From Example 10, $a = \frac{m_2 - m_1}{m_2 + m_1} g = \frac{1000\ \text{kg} - 1200\ \text{kg}}{2200\ \text{kg}} \times (9.81\ \text{m/s}^2) = \underline{-0.892\ \text{m/s}^2}$.

The - sign means the acceleration of the cage points *down*.

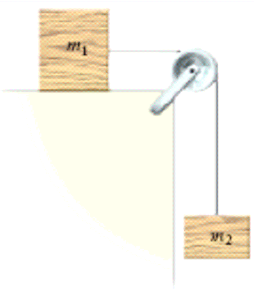
$v = v_0 + at \Rightarrow \underline{t = \frac{v - v_0}{a} = \frac{0 - 1.5\ \text{m/s}}{-0.892\ \text{m/s}^2} = 1.7\ \text{s}}.$

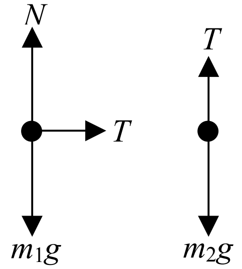
(b) From Example 10,

$T - m_1 g = m_1 a \Rightarrow T = m_1(g + a) = (1200\ \ kg)\left(9.81\ \text{m/s}^2 - 0.892\ \text{m/s}^2\right) = \underline{1.07 \times 10^4\ \text{N}}.$

(c) When the brakes are locked, the acceleration of the car and the counterweight is zero. The net force on each object must be zero, so the upward force on the counterweight is equal to its own weight. Therefore the tension in the cable is 1000 kg × 9.81 m/s^2 = $\underline{9.81 \times 10^3\ \text{N}}$.

†5-93.

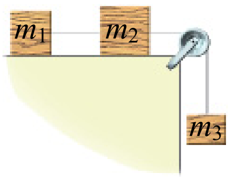


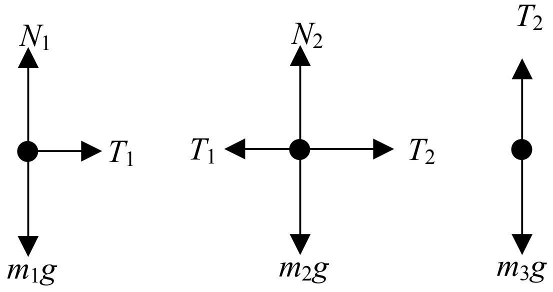


(a) Take the *x* direction to point right and the *y* direction to point up. Newton's Second Law for m_1 gives $\sum F_y = N - m_1 g = 0$, $\sum F_x = T = m_1 a_1$. For m_2, $\sum F_y = T - m_2 g = m_2 a_2$. If the string passing over the pulley does not stretch and has negligible mass, then the magnitude of a_2 must be the same as the magnitude of a_1. If m_1 moves in the +*x* direction, then m_2 must move in the −*y* direction, which means $a_2 = -a_1$. Then the equations for $\sum F_x$ for m_1 and $\sum F_y$ for m_2 can be combined to give an equation for a_1: $\underline{a_1 = \frac{m_2 g}{m_1 + m_2}}$.

(b) The equation for $\sum F_x$ gives the tension: $\underline{T = m_1 a_1 = \frac{m_1 m_2 g}{m_1 + m_2}}$.

5-94.





Three "free-body" diagrams are required. Take the *x* direction to point right and the *y* direction to point up. The sums of forces in the *y* direction are zero for m_1 and m_2 and give no useful information about the motion. $\sum F_x$ for m_1 and m_2 and $\sum F_y$ for m_3 will give the acceleration and tensions.

(a) $T_1 = m_1 a_1$

$T_2 - T_1 = m_2 a_2$

$T_2 - m_3 g = m_3 a_3$

If the strings don't stretch, then all three accelerations must have the same magnitude. The accelerations for m_1 and m_2 must also have the same direction, and if m_1 and m_2 are accelerating in the $+x$ direction then m_3 must be accelerating in the $-y$ direction. Thus we have $a_2 = a_1$ and $a_3 = -a_1$. Subtracting the second equation from the first eliminates T_1, and subtracting the third equation from that result eliminates T_2, leaving an equation for a_1: $\underline{a_1 = \dfrac{m_3 g}{m_1 + m_2 + m_3}}$.

(b) The first equation gives T_1: $\underline{T_1 = \dfrac{m_1 m_3 g}{m_1 + m_2 + m_3}}$. The second equation gives T_2:

$T_2 = T_1 + m_2 a_1 = \dfrac{m_1 m_3 g}{m_1 + m_2 + m_3} + \dfrac{m_2 m_3 g}{m_1 + m_2 + m_3}$, or $\underline{T_2 = \dfrac{m_3(m_1 + m_2)g}{m_1 + m_2 + m_3}}$.